Tornado Warning Guidance: Spring 2002

I. INTRODUCTION

The Warning Decision Training Branch (WDTB) is providing a tornado warning guidance training package that is intended to help forecasters make the best use of scientific findings, technology, and the human element in formulating more effective tornado warnings.

The training is composed of three elements:

1. **Tornado Warning General Guidance**
2. **Radar Algorithm Statistics from NSSL study**
3. **Teletraining session**

It is hoped that every forecaster takes the opportunity to read through the general guidance document, which contains some very useful information regarding the latest research from VORTEX on tornadogenesis including near-storm environment considerations, radar signatures, and algorithm applications. This section, as is all the tornado warning guidance training components, should help forecasters with the difficult problems in discriminating between storms that produce tornadoes and those that do not.

The statistical analysis of radar derived parameters is from NSSL 2001 results of analyzing numerous radar data using NSSL's Mesocyclone Detection Algorithm and the Tornado Detection Algorithm. Over 100 radar derived parameters were analyzed to discover important radar signature relationships to tornado occurrence. Numerous graphs are presented which depict parameter frequency distributions and relative skill values in using individual and combinations of radar derived parameters. This section is provided as a separate document: Tornado Warning Guidance based on an Analysis of MDA/TDA/NSE Data, available at http://wdtb.noaa.gov/resources/PAPERS/twg02/twg2001stats.pdf.

Finally, the third component is teletraining, led by Jim LaDue of the WDTB. Jim describes some of the latest Near-Storm Environment (NSE) considerations to the tornado discrimination problem and discusses the basic ingredients for tornadogenesis. He also illustrates various radar depictions of tornadic storms. At the end of the session, the instructor facilitates a series of mini case exercises so participants can apply what they've learned.

Forecasters can sign up for the teletraining session from the VISIT teletraining calender. The student guide for the session is at:
http://www.cira.colostate.edu/ramm/visit/twg.html

Additional professional development training on severe convection and the convective warning process can be found from this WDTB web site:
http://www.wdtb.noaa.gov/resources/PDS/newconvectpds.htm

II. GENERAL GUIDANCE

This general guidance is presented from analyses of VORTEX data and a mix of other peer reviewed research and qualitative observations concerning tornado warning decision making. This document will continue to be updated as observations are quantified and validated through the scientific method. It is based specifically on three sources of data:

1. **published papers** on observations of tornadic storms during VORTEX,
2. **applied research** utilizing a number of WSR-88D case studies, and
3. **observations** during NWS warning operations, operational real-time tests of the NSSL Warning Decision Support System (WDSS), and Warning Decision Training Branch (WDTB) workshops.

NWS warning forecasters are challenged with distinguishing which storms are tornadic or non-tornadic (or severe or non-severe) with the information available. Whenever possible, one should not rely solely on radar data for making warning decisions, as even storms having strong low-altitude mesocyclones may not produce a tornado (this was observed several times during VORTEX). Warning forecasters should integrate information from a variety of sources, including Doppler radar data from ***multiple*** radars (when available), algorithm guidance, reliable spotter reports, storm history, remote sensing instruments (surface, satellite, and lighting observations), statistical knowledge of past events, a basic understanding of storm physics, and have a good understanding of the Near-Storm Environment (NSE). This requires acute situational awareness, and is essential in the integrated warning system. The following are sections of warning guidance considerations grouped by category.

A. NEAR-STORM ENVIRONMENTAL CONSIDERATIONS

Some VORTEX scientists suggest that three main ingredients are essential for the development of significant (F2 or greater) tornadoes. These three ingredients, which must exist simultaneously in the storm and its associated environment, are enhanced ***Storm-Relative Helicity (SRH), "special" Rear-Flank Downdraft (RFD) characteristics, and a persistent updraft***. The co-existence of these three ingredients is much more important than their individual strengths. The limitations in adequately measuring these ingredients create problems operationally in monitoring the immediate NSE. However, skill in recognizing some mesoscale approximations to these ingredients is an important facet to successful tornado warning decision making. Continual mesoanalysis of these approximations is very important because the values can vary dramatically over fairly short distances and are subject to rapid changes (this was observed on many VORTEX storm days; see Markowski et al. 1998a).

In terms of the helicity "ingredient", supercells tend to produce significant tornadoes in regions with enhanced **near-ground SRH**. In many situations, enhanced low-altitude SRH will be associated with locally backed and strengthened surface winds. This SRH enhancement can be on the order of from 200 to 300 m^2/s^2 initially to near 1000 m^2/s^2 over a very short distance prior to tornadogenesis. The magnitude of this enhancement was observed in some VORTEX cases. All available low-altitude wind data should be monitored, including routine surface observations, mesonet data, lowest-tilt radial velocity, and wind profiler data (where available).

Note: **Caution must be applied when using any environmental data sets on AWIPS, especially high-resolution model objective analyses. Because of known AWIPS smoothing and filtering degradations resulting from limitations in displaying the full horizontal and vertical resolution of the model grids, plus differences in the computation of various parameters such as CAPE and SRH, significant errors and potential bad decisions can result from misapplication of particular NSE variables into the warning process. Model analysis should always be verified by observations.**

Because of baroclinic effects along shallow boundaries, the immediate **cool side of the boundary** is often an area of strongly enhanced horizontal vorticity (Markowski et al. 1998b). In many situations where significant tornadoes (>F1) occur, meso-beta scale enhancement of low-level SRH, or the combination of low-level SRH and CAPE, as quantified by parameters such as Vorticity Generation Parameter (VGP) or Energy Helicity Index (EHI), develops in conjunction with baroclinic boundaries. This augmentation occurs above what is normally observed in synoptic scale environments associated with tornado outbreaks. Thus, closely monitor storms moving into areas of enhanced low-level SRH and CAPE based on integrated sensor analysis. Even lacking wind and temperature data, the mere presence of a boundary should lead to heightened awareness, and storms crossing or interacting with boundaries merit special scrutiny for rapid increases in rotation in their lower altitudes. This implies that forecasters need to remain aware of the locations of radar fine lines, satellite-indicated cloud lines, and mesonet-detected surface temperature gradients and wind-shift lines. On occasion, horizontal vorticity may be locally augmented several hours after all evidence of a near-surface thermal gradient has disappeared. Therefore, weakening thermal boundaries may have fewer clues to their existence and yet still contain an extremely favorable combination of enhanced low-level SRH and high values of surface-based CAPE (Rasmussen, personal communication). Exercise heightened awareness on storms interacting with boundaries - these should be closely monitored because the likelihood for tornadogenesis is greater for storms interacting with boundaries. Although many storm-boundary interactions do not result in tornadoes, if rapid mesocyclogenesis is observed in the radar data after boundary interaction, a tornado warning most likely **should be issued**.

The chances for significant tornadoes on the cool side of boundaries decrease as low-altitude cold air becomes increasingly stable with respect to surface-based convection (e.g, surface-based CAPE decreases and surface-based CIN increases). These parameters are difficult to assess in real time, but the key fact is that if the air still contains some significant surface-based CAPE (SBCAPE), despite being relatively cool, the potential for significant tornadoes exists in areas where the enhanced helicity resides near the ground. The width on the cool side of a boundary where these favorable conditions reside varies dramatically from just a few kilometers to as much as several hundred kilometers. Analyze the width of the boundary via surface observations that continue to yield significant SBCAPE. In addition, monitor the character of boundary-layer clouds from satellite. Clouds that appear highly stratiform are indicative of stabilized air which may decrease the tornado potential whereas the presence of more convective boundary layer clouds supported by strong instability based on surface data, may indicate a favorable environment for tornadic storms.

Surface boundaries exhibiting strong vertical vorticity underneath a rapidly developing storm updraft may be a potential area for tornadogenesis of the “landspout” variety of non-supercell tornado (Wakimoto and Wilson, 1989). These types of tornadoes are typically too small to be observable by base velocity or storm-relative motion 88D products, even at close ranges (< 20 nm). However, boundaries with high vertical vorticity can be observed using a combination of base velocity and surface observations. In the event a boundary is unable to be detected by radar, GOES-8 imagery and surface data can be used to analyze boundaries with high vertical vorticity. The WSR-88D can then be used to locate rapidly developing storms. Szoke and Brady (1989) suggested that increases in midlevel reflectivities of 20-35 dBZ over a 5 minute period strongly indicated rapid storm updraft development in progress. Maintain a heightened awareness for potential landspout tornadoes upon seeing the superposition of a vertical vorticity rich boundary with rapid updraft development.

B. REAR FLANK DOWNDRAFT CHARACTERISTICS

The thermodynamic characteristics of the rear flank downdraft (RFD) also appear to be important to significant supercell tornadogenesis of F2 strength or greater (See Markowski, 2000). RFDs that possess a relatively low equivalent potential temperature (θ_e) deficit between its source region and the surface are more likely to enhance tornadogenesis. In addition, tornadogenesis is more likely as the potential buoyancy (CAPE) in the RFD increase, and as the CIN associated with RFD parcels at the surface decreases. Since direct surface measurements of RFDs are not routinely available, rough mesoscale approximations for enhanced surface humidities in the vicinity of tornadic-associated RFDs are small surface temperature/dew-point temperature spreads and low Lifting Condensation Levels (LCLs). According to Rasmussen and Blanchard (1998), the median LCL for significant tornado sounding dataset was 780 m and for nontornadic supercells, 1230 m above ground-level. LCLs above 1500 m have rarely been associated with significant tornadoes. However, there are also a significant number of nontornadic supercells with low LCLs. Additionally, as there is only a 64% correlation between LCL heights and RFD θ_v deficits, as reported by Markowski et al. (2002), other processes and parameters influence the eventual thermodynamic characteristics of RFDs.

To properly use LCL height as an RFD proxy, remember that low LCLs do not increase the tornado threat of a supercell by themselves. However, the presence of high (>1500m) LCLs, even with other parameters favorable for tornadoes, may be enough to dramatically lower the probabilities of a supercell to initiate significant tornadoes. Weaker tornadoes that are still significant from a tornado warning decision standpoint are not as well correlated with LCL or even RFD θ_e deficits. Finally, there is no established relationship between LCL heights and non-supercell tornadoes.

C. RADAR SIGNATURES

Be aware that some storms with midlevel mesocyclones may produce tornadoes rapidly with little advance warning in the way of an algorithm identified Tornado Vortex Signatures (TVS) or rotation at the 0.5° volume scan. Often, the only low-altitude precursor from radar in these situations is an area of strong, low-altitude (0-2 km AGL) convergence (Burgess and Magsig, 1998) below the base of the organizing mesocyclone (remember that 0-2 km AGL information is only observable out to about 65 nm). Also, second and succeeding mesocyclone cores (cyclic mesocyclogenesis) typically have very short organizing stages as they quickly form over a large depth and strengthen rapidly. Therefore, explosive development can take place during the period of a single volume scan. The opposite (rapid dissipation) was also observed during VORTEX.

Not every TVS forms at mid altitudes and builds downward over time with the embryonic tornado. Trapp et al. (1998) observed that some TVSs develop rapidly near the surface or simultaneously at low and mid altitudes. Most squall-lines and 48% of supercells exhibited non-descending TVS development. Be aware of both types of TVS development, and anticipate low-altitude development with squall lines.

Radar-observable vortex signatures which are associated with tornadoes can occur with a variety of storm types. These range from the classic Great Plains supercell (with large horizontal and vertical extent) as well as supercells with small horizontal extent (mini supercells), supercells with small vertical extent (low-topped supercells), or both (low-topped mini supercells). Tornadoes and radar-observable vortex signatures have also been observed with storms embedded within tropical cyclone rain bands (“TC-mesos”), along the leading edge and comma head of bow-echo squall lines, and with rapidly-developing convection (non-supercell tornadoes, landspouts, waterspouts). Do not be misled into believing that all supercells resemble the classic big isolated supercells more common to the Central and Southern Plains. Be aware that many varieties exist, including some that probably have not yet been observed. NSSL maintains a WSR-88D Mesocyclone and tornado signature case study page that contains the description (with figures) of a number of these typical and atypical tornadic storm cases.

In many instances, the radar-observed vortex signature can, depending on range, appear to dissipate ***prior to*** the actual dissipation of the tornado, as the shrunken tornado vortex (or tornado cyclone) becomes increasingly difficult to observe given WSR-88D sampling limitations. This period without a radar-observable vortex signature ***may*** include the most intense and damaging phase of the tornado. Occasionally, the storm may appear to be rapidly weakening and the last evidence of a former updraft may be the persisting tornado. It is a good rule of thumb to continue tornado warnings for a few volume scans following the dissipation of the radar-observed vortex signature, especially in the absence of reliable spotter information and/or during nighttime hours.

D. RADAR SAMPLING CONSIDERATIONS

Data collected during VORTEX using the Doppler On Wheels (DOW), and data from a variety of WATADS-analyzed WSR-88D cases, verify that a variety of vortex scales occur within storms, ranging from the scale of the actual tornado (and even its sub-vortices), up to the scale of the rotating updraft/downdraft of the supercell storm (mesocyclone), with vortices intermediate to these scales also occurring (sometimes referred to as the tornado cyclone). Some data suggest that these vortices may be embedded within each other, or that some vortices may taper or widen in diameter at different heights. Radar users should be aware that the WSR-88D, with its inherent sampling limitations, may detect a mixture of these kinds of vortices. Operators should also be aware that only in very rare instances can the WSR-88D actually observe the actual tornado, again, owing to the sampling limitations of the radar (the tornado must be very large and/or very close to the radar). In most instances, a TVS is actually the signature of an intermediate-scale vortex, observed as a gate-to-gate velocity couplet. See Burgess et al. (2001) for examples of this during the May 3, 1999 Tornadoes.

Because the WSR-88D provides only discrete horizontal samples of the atmosphere (1° azimuthal resolution; 1 km and 250 m range resolution for reflectivity and velocity respectively), storm-scale vortices can only be depicted in a degraded sense (Wood and Brown 1997). Factors include vortex core diameter to beam width radius ratio, strength of rotation in the vortex, and the offset between the vortex centroid and the centroid of the radar beam. A particular vortex of a given diameter and rotational velocity could be viewed by the radar in a number of configurations given its range from the radar and the vortex/beam centroid offsets. And, if a vortex is shaped asymmetrically, changes in viewing angle will also alter its radar depiction. Consider that these sampling limitations will reduce the velocity estimate of the vortex. Consult Wood and Brown (1997) for information depicting the degree of velocity degradation in radar-sampled vortices.

At extended ranges, the radar horizon prevents sampling below the mid-altitudes of mesocyclones. Thus, the radar may observe mid-altitude rotation that is strong for storms at extended ranges, but the radar cannot determine if the low-altitude rotation is strong or even exists. Users should employ the use of spotter reports, or data from another radar sampling the signature from a closer range. At near ranges, the “cone-of-silence” effect will prevent sampling of vortices above a certain altitude, and only a portion of the vortex can be diagnosed for warnings. Forecasters should use data from other WSR-88Ds at farther ranges to sample the mid- and high-altitude data being missed in the cone-of-silence.

Many algorithm-detected radar-observable vortex signatures (both mid-altitude and low-altitude) are ***NOT*** associated with tornadoes on the ground. Bear in mind that in some instances, atmospheric vortices can be too small (owing to sampling limitations), or hidden by radar data artifacts (such as range-folded data). Radar algorithms cannot detect these unobservable vortices. The function of the TDA is to diagnose the attributes of detected vortices to determine the probability that they are associated with tornadoes. ***It is extremely important to understand that the presence of a TVS or mesocyclone does not imply the presence of a tornado (they are tornadic only 20-40% of the time according to the latest statistics).*** In addition, some vortex detections in TDA may be the result of dealiasing errors, leading to false diagnoses. Ultimately, the user should always examine other base data (velocity images) as well as other information (NSE, spotters, trends, other algorithm data) to make the eventual tornado warning determination.

E. ALGORITHM PERFORMANCE

Adaptable parameter sets are provided with the Tornado Detection Algorithm (TDA) that correspond to a variety of storm types. It is important to understand that storm types are a factor of the storm's mesoscale or near-storm environment (NSE), and NOT due to the region of the U.S. that the storm is occurring. The NSE should be closely monitored during warning operations so that the proper adaptable parameter sets are always used. Keeping adaptable parameter settings at some site-selected default value because of regional expectations of a certain storm type (i.e., mini supercells always occur in the Northeast) may result in poor algorithm performance if the prevailing NSE does not correspond to the default settings. For example, if an NSE supportive of large and tall (“Oklahoma-style”) supercells is occurring in New York, use the TDA adaptable parameter developed for these types of storms.

F. STORM MOTION CONSIDERATIONS

Storm motion and tornado motion (direction and speed) may be significantly different. For example, on two VORTEX days (6/2/95 and 6/8/95), there were several instances where the parent thunderstorm was moving toward the northeast while the tornado was moving north. In addition, for another case, the tornado's forward movement was measured at 60 mph only to become nearly stationary before it dissipated. Be careful about issuing tornado warning locations based on the storm cell centroid motions; use the motion of the radar vortex signature, whenever available, and allow adequate room to allow for uncertain (and non-linear) tornado motion.

G. SPOTTER REPORTS

Consider the reporting conditions when evaluating spotter information. For example, spotter reports may be less reliable in HP storm environments or at night than when reports occur in conditions offering an unobstructed view of a classic supercell updraft in daylight. Do not discontinue a tornado warning based upon the lack of a confirmed sighting of a tornado in questionable viewing conditions. Likewise, if a report of a tornado arrives without any supporting evidence in any operational dataset, more confirmation is advisable before a tornado warning is issued. To summarize, be aware of the quality of your spotter reports given the quality of viewing conditions and spotter reputation.

H. MISCELLANEOUS

When issuing a warning based on radar, remember the total time involved includes: viewing and analyzing the radar vortex signature (this can take any-where from 1 minute to 6 minutes if you are using algorithm products as guidance, as they are generated at the end of a volume scan), mechanically composing the warning message (2-3 min., or 1 min. if using AWIPS), and disseminating the warning (1 min. or more). With the possible lapse of 3 to 10 minutes of time, the location of the mesocyclone or Tornadic Vortex Signature (TVS) that triggered the decision to issue the warning could have moved a considerable distance. Thus, this translated distance of the signature needs to be taken into account when locations are mentioned in the warning (especially when using algorithm overlays for location guidance). This translated distance also needs to be considered for warnings in downstream counties.

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